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THE EFFECT OF A PLANETARY SURFACE PENETRATOR ON THE SOIL COLUMN SURROUNDING THE IMPACTING BODY

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Planetary surface penetrators are being considered for future space missions. One question that must be answered before penetrators can be used is: "What effect does a penetrator cause on the impacted soil column?" To evaluate this question further, a prototype penetrator instrument was impacted into a dry lake bed. Laboratory studies of the soil surrounding the penetrator revealed that the soil was contaminated by paint and metal from the penetrator's casing. Paint pigment rich in titanium and sulfur was found in the adjacent soil. The highly mobile paint pigment migrated onto viewing ports in the penetrator's exterior. Bulk analysis of the soil adjacent to the impactor showed a significant increase in both elements, as well as the presence of metal chips from the casing and nose cone. It is recommended that great care be taken in the use of coating materials and the metal alloys selected for the penetrator's exterior. Otherwise, the accuracy of any experiment requiring an uncontaminated *in situ* sample (i.e., onboard X-ray fluorescence experiment) may be adversely affected.

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ABSTRACT

Planetary surface penetrators are being considered for future space missions. One question that must be answered before penetrators can be used is: "What effect does a penetrator cause on the impacted soil column?" To evaluate this question further, a prototype penetrator instrument was impacted into a dry lake bed. Laboratory studies of the soil surrounding the penetrator revealed that the soil was contaminated by paint and metal from the penetrator's casing. Paint pigment rich in titanium and sulfur was found in the adjacent soil. The highly mobile paint pigment migrated onto viewing ports in the penetrator's exterior. Bulk analysis of the soil adjacent to the impactor showed a significant increase in both elements, as well as the presence of metal chips from the casing and nose cone. It is recommended that great care be taken in the use of coating materials and the metal alloys selected for the penetrator's exterior. Otherwise, the accuracy of any experiment requiring an uncontaminated *in situ* sample (i.e., onboard X-ray fluorescence experiment) may be adversely affected.

INTRODUCTION

Additional NASA programs for the exploration of Mars and other planetary bodies are now being planned beyond the 1976 Viking mission. One of these programs proposes a series of Pioneer multi-penetrator missions (NASA unpublished reports, August 1974 and February 1975). Such a penetrator mission would involve a payload consisting of four, six, or nine penetrators. Each penetrator would include instruments capable of measuring parameters such as seismic activity, subsurface chemistry, water, heat flow, wind speed, temperature, and surface pressure. The penetrators could be fired individually into preselected surface sites of scientific interest. Once implanted, they would supply data for periods of time varying from days to years.

One of the problems that must be examined for such a mission is the effect a penetrator would have on the soil column it penetrates. To study this and other related problems, a prototype penetrator was launched and impacted

0.9 to 1.2 m (3 to 4 ft) into a dry lake bed in the desert. After removal from the lake bed, the penetrator was brought to Ames Research Center for study.

The purpose of this paper is to determine if the action caused by the penetrator impacting the soil column produced abraded debris that could contaminate the original soil and thereby jeopardize an *in situ* analysis performed by certain types of analytical instruments (i.e., X-ray fluorescence or spectral reflectance) that might be onboard the penetrator.

PROCEDURE

The soil was examined using stereo and bright field microscopy to obtain a visual appraisal of the soil immediately adjacent to the penetrator's skin. Scanning electron microscopy (SEM) was used to examine individual particle morphology. X-ray analysis (using the SEM) of individual particles was performed to determine the elemental composition of the abraded particles in the soil from the penetrator's skin. X-ray fluorescence analysis was used to determine if the contamination level was so high that it affected a bulk analysis.

RESULTS

Soil samples immediately adjacent to the penetrator casing were carefully removed from several sites, as shown in figure 1. Selected fragments of paint and casing material were also removed for examination. Optical microscopic examination of the soil samples showed that much of the soil surface adjacent to the casing was coated with red paint (fig. 2). The paint came from the outer surface of the penetrator casing. Not so apparent was a white paint covering parts of the soil surface as well as part of the red paint. The white paint was evidently a primer placed directly over the metal of the penetrator casing before the red paint was added. The soil surface in direct contact with the casing was very smooth and striated. The paint had been smeared in parallel streaks that were thicker in some places than others. The larger soil grains were usually not fractured by impact. Instead, they appeared to be pushed back into the softer matrix material. Some shiny particles of abraded metal could be seen adhering to larger soil grains. The metallic particles represent portions of casing metal that had been scoured off as the impactor penetrated the soil column. Figure 2 shows a surface where paint has built up over the soil and some metal has scraped off the casing.

Cracks in the soil perpendicular to the penetrator's entry axis were common. These cracks are caused by the rebounding soil after the compression wave formed during the penetrator's entry into the soil. Frequently the paint pigment (figs. 3(a) and (b)) migrated into these cracks where it coated and/or completely filled them. Thus, the paint pigment appears to be mobile during the penetration: it smears off the penetrator's metal casing and coats

the adjacent soil surface as it passes through the soil column. The smeared paint pigment has also partially covered one viewing port on the side of the impactor, as shown in figure 4. The port was set back from the skin line, thus allowing the abraded debris to build up. Occasionally, portions of smeared paint show a vesicular texture (fig. 5). This texture indicates sufficient heat was generated during penetration to melt the paint.

Chips of red and white paint, casing metal, and nose cone metal were removed from the penetrator using a silicon carbide scribe. The chips were analyzed for their elemental composition using an X-ray emission attachment on the scanning electron microscope. Figure 6(a) shows the composition of the white paint, and figure 6(b) shows the composition of the red paint. The primary difference between the two paints is the concentrations of titanium and sulfur. The white paint is high in titanium and the red paint is high in sulfur. The composition of the nose cone and casing body metal appear nearly identical, as shown in figure 7. Both are high in iron, with a trace of manganese. Soil samples adjacent to the penetrator housing were prepared for X-ray fluorescence analysis in two ways: one sample (inner surface) was soil adhering directly to the face of the penetrator casing; the second sample (outer surface) was soil 1.27 to 1.91 cm (0.5 to 0.75 in.) away from the penetrator's casing. Samples of both materials were carefully removed from the penetrator casing and placed in their respective X-ray sample holders. The two samples were then analyzed for their elemental composition using standard X-ray fluorescence techniques. The analytical results are shown in table 1. The X-ray fluorescence scans (fig. 8) show a definite peak for sulfur in low concentrations, along with a significant peak for titanium content of the inner soil. All values are qualitative and no figures can be given for percentage concentrations from these results. No apparent increase in iron was noted between the two surfaces.

RECOMMENDATIONS

The preceding data appear to show that paint pigment covering the surface of the penetrator is mixing with the soil surface as the penetrator moves through the soil column. The paint also appears quite mobile (melts) during the penetration. This mobility results in an uneven distribution of paint pigment in the soil and allows a significant buildup in soil cracks adjacent to the casing face. The paint also smears and coats the viewing ports on the penetrator's housing. The design of these ports requires special attention to ensure they will not degrade and adversely affect onboard experiment packages designed to perform *in situ* analysis of soil. A significant buildup of titanium and sulfur indicates that the true picture of the soil column is not present directly adjacent to the penetrator body. Instead, it is being contaminated by elements present in the paint. Also, contamination from the metal casing has been demonstrated, but at much lower levels.

This study suggests that great care be taken in the use of coating materials and the metal alloys selected for the penetrator's exterior casing. Otherwise, the accuracy of any experiment requiring an uncontaminated *in situ*

sample will be seriously affected. Future design and testing of penetrator configurations should be accompanied by careful analytical studies. The studies should include both the penetrator casing surface and the soil attached to the casing.

REFERENCES

1. Mars Science Missions in the Post Viking Era: Possible Contributions of Pioneer Type Missions, August 1974 (NASA unpublished report).

2. Mars Surface Penetrator Mission Instrument Status, February 1975 (NASA unpublished report).

TABLE 1.— COMPARISON OF ELEMENTAL COMPOSITION BETWEEN INNER AND OUTER SOIL LAYERS

Element	Qualitative amount	
	Outer	Inner
Ca	High	High
K	Medium	Medium
Si	Medium	Medium
Ti	Medium to low	High
Fe	Medium to low	Medium to low
P	Medium to low	Medium to low
Sr	Low	Low
S	Trace	Low
Cu	Trace	Trace
Zn	Trace	Trace
Cl	Trace	Trace

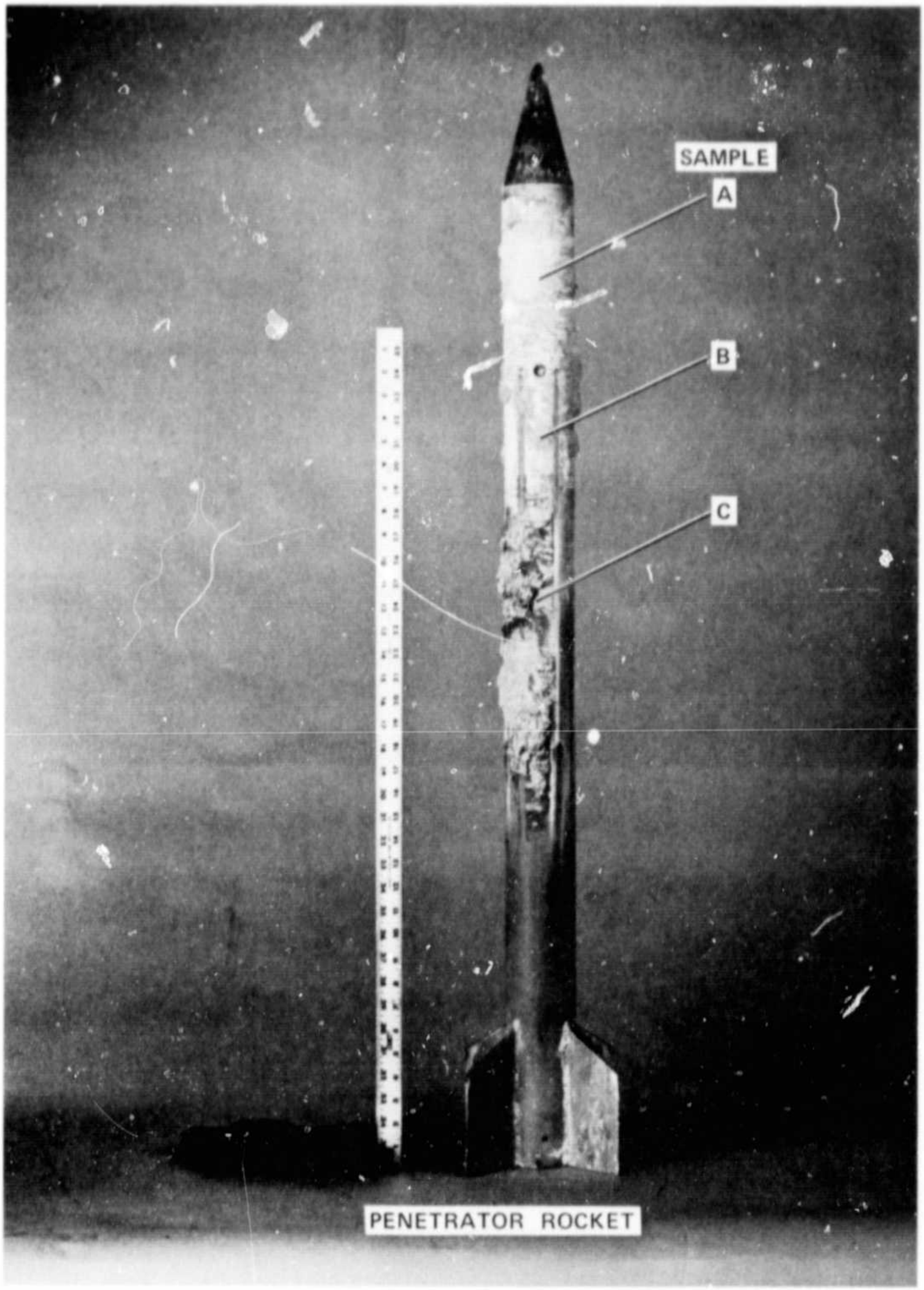

Figure 1.— Penetrator casing after impacting into dry lake bed. Samples of soil were removed from penetrator surface at locations A, B, and C for analyses. Also, material was scraped from the penetrator casing to compare with the samples.

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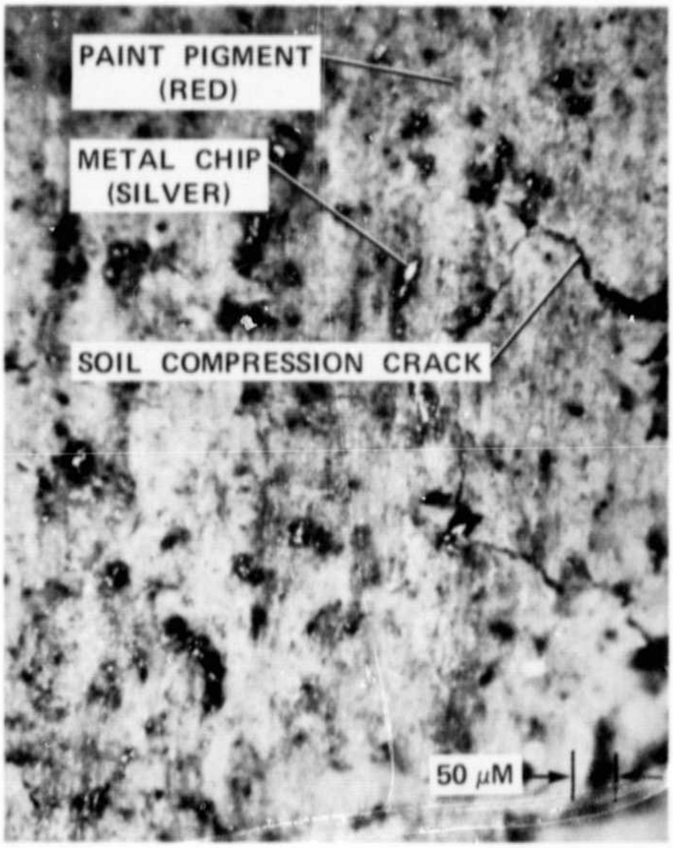
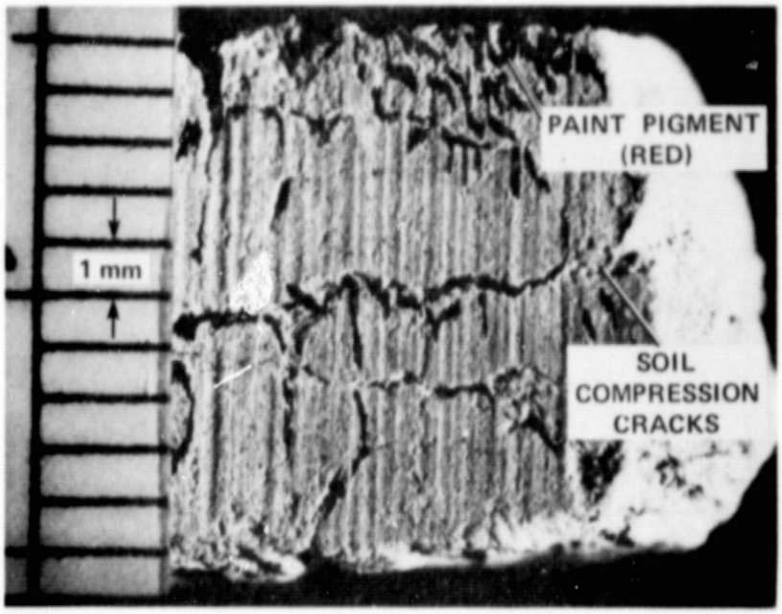
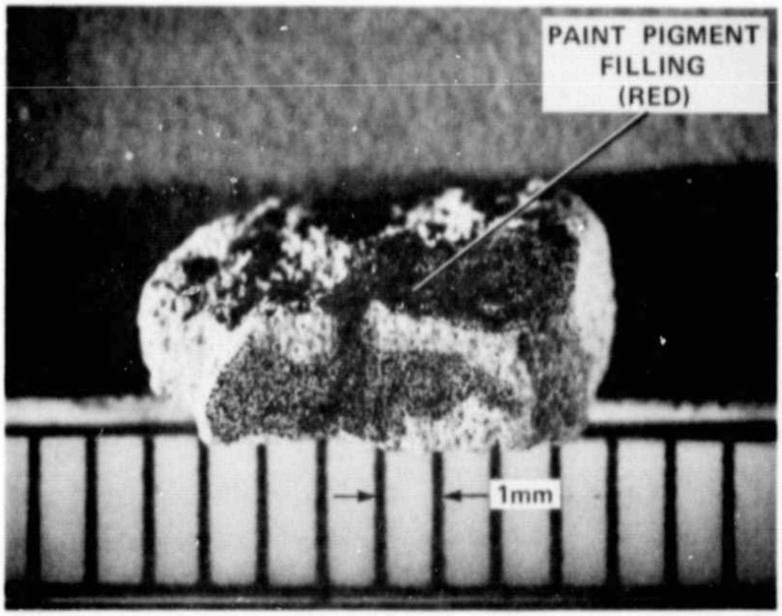


Figure 2.— Photomicrograph of soil immediately adjacent to the penetrator's casing. The red and white streaks are paint from the penetrator's outer coating. The metal chips are pieces of metal from the nose cone and casing body that were scraped off during impact (230X).



(a)



(b)

Figure 3.— Photomacrograph of the soil immediately adjacent to the penetrator's casing showing the cracks caused by the rebounding soil after the compression wave formed during the penetrator's entry into the soil. During the time of formation, these cracks were filled by the mobile point pigment which came from the protective coating on the exterior of the penetrator's casing. View A is looking directly at the face between the casing and soil boundary. View B shows paint that migrated into a crack.

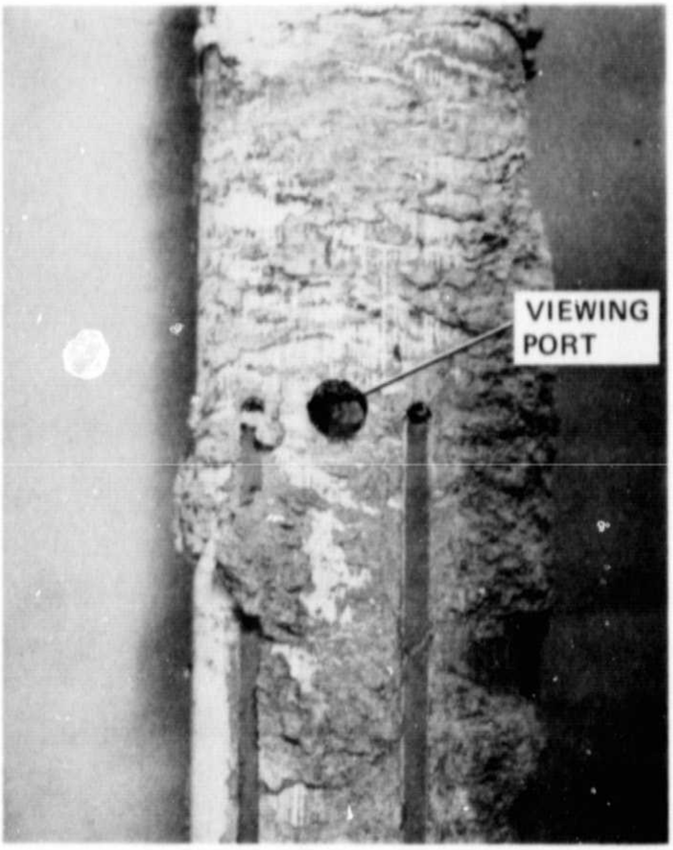
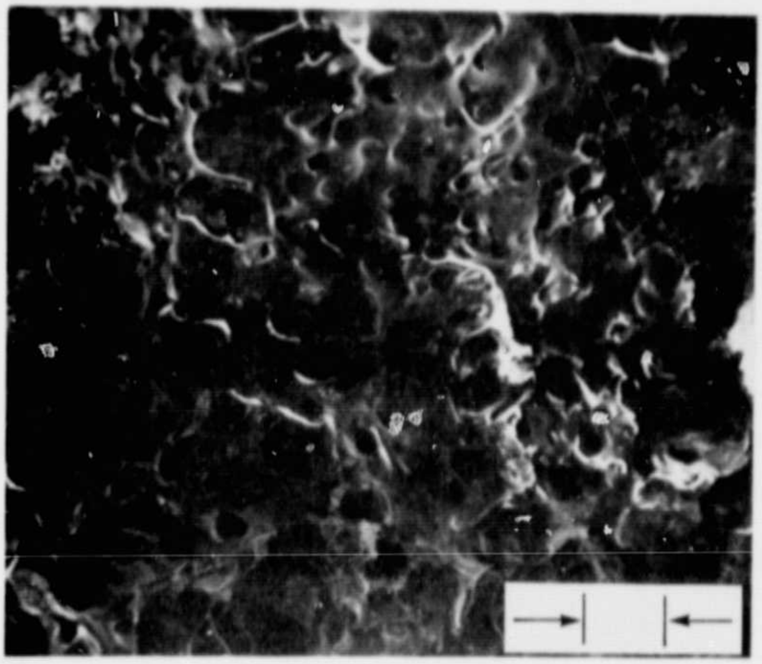
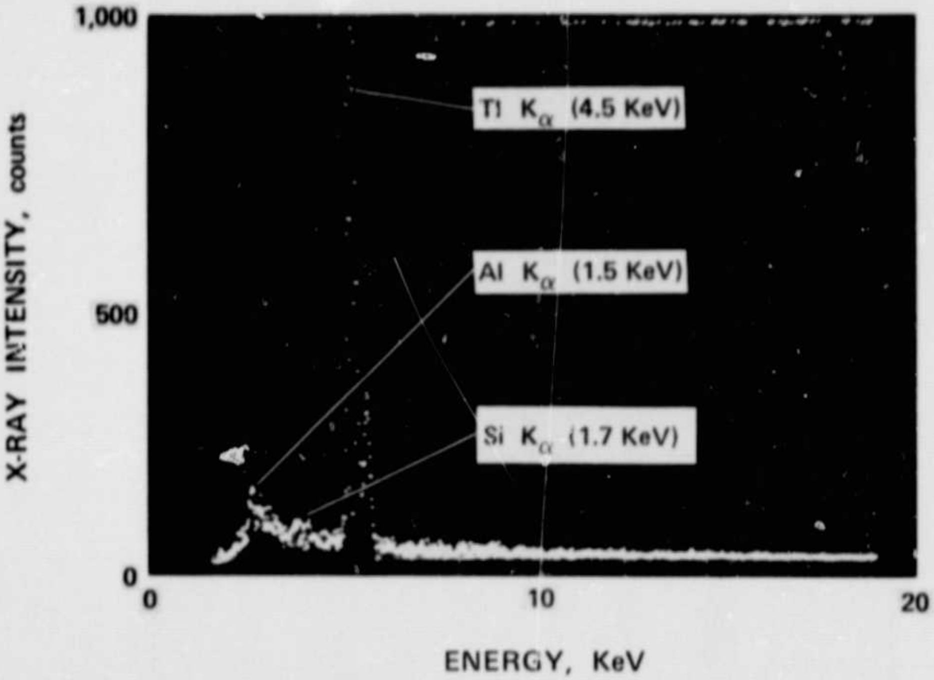


Figure 4.– Photo of penetrator casing showing the buildup of debris smeared over the viewing port.

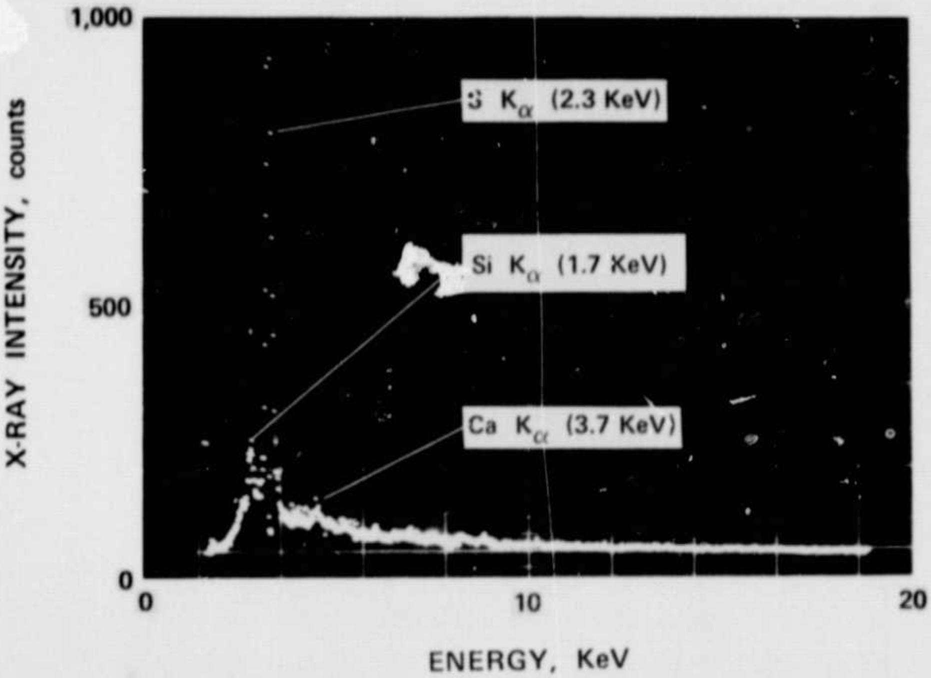


100μM

Figure 5.— Scanning electron microscope image of the vesicular texture produced by the melted paint coating the viewing port (100X).

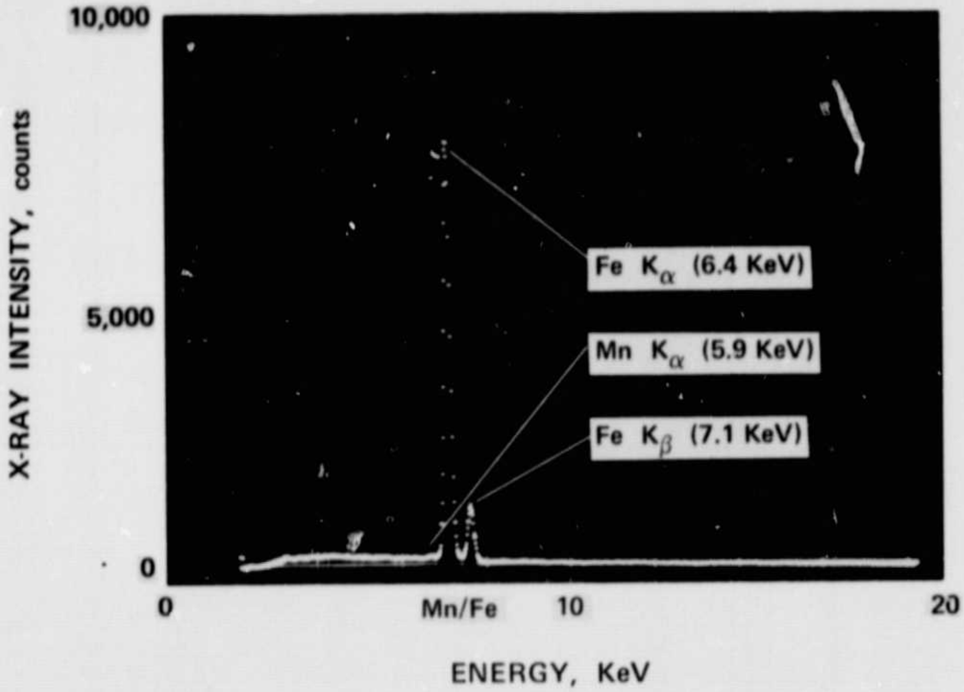


(a) Identifies elements Al, Si, and Ti, which are in the pigment for the white paint.

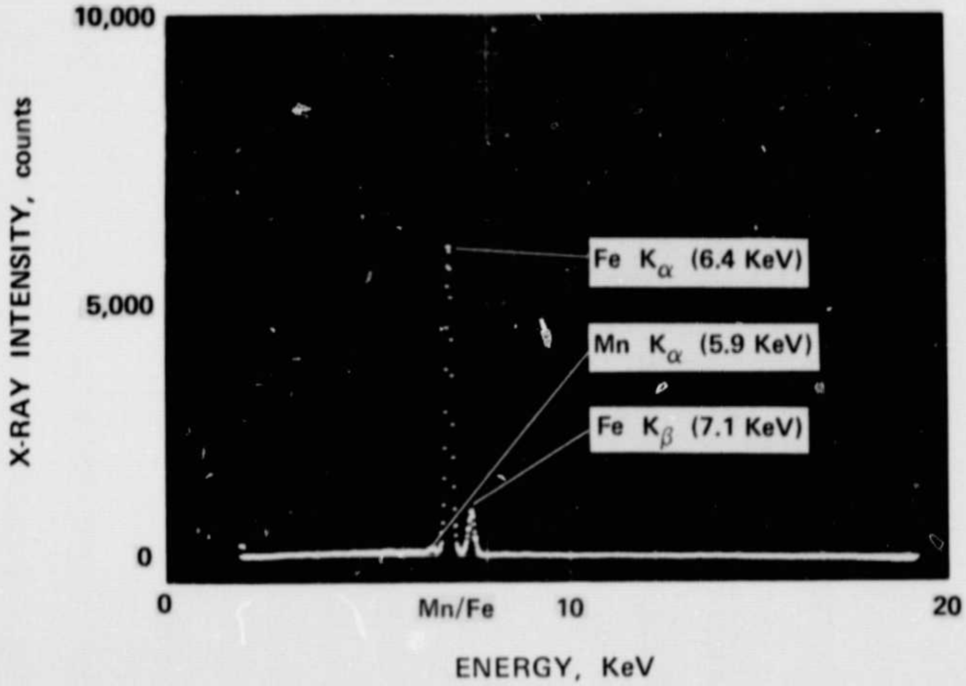


(b) Identifies elements Si, S, and Ca, which are in the pigment for the red paint.

Figure 6.— Photos of CRT display delineating the number of X-ray photons counted from the paint sample in 200 sec time and the energy of the emitted X-rays.

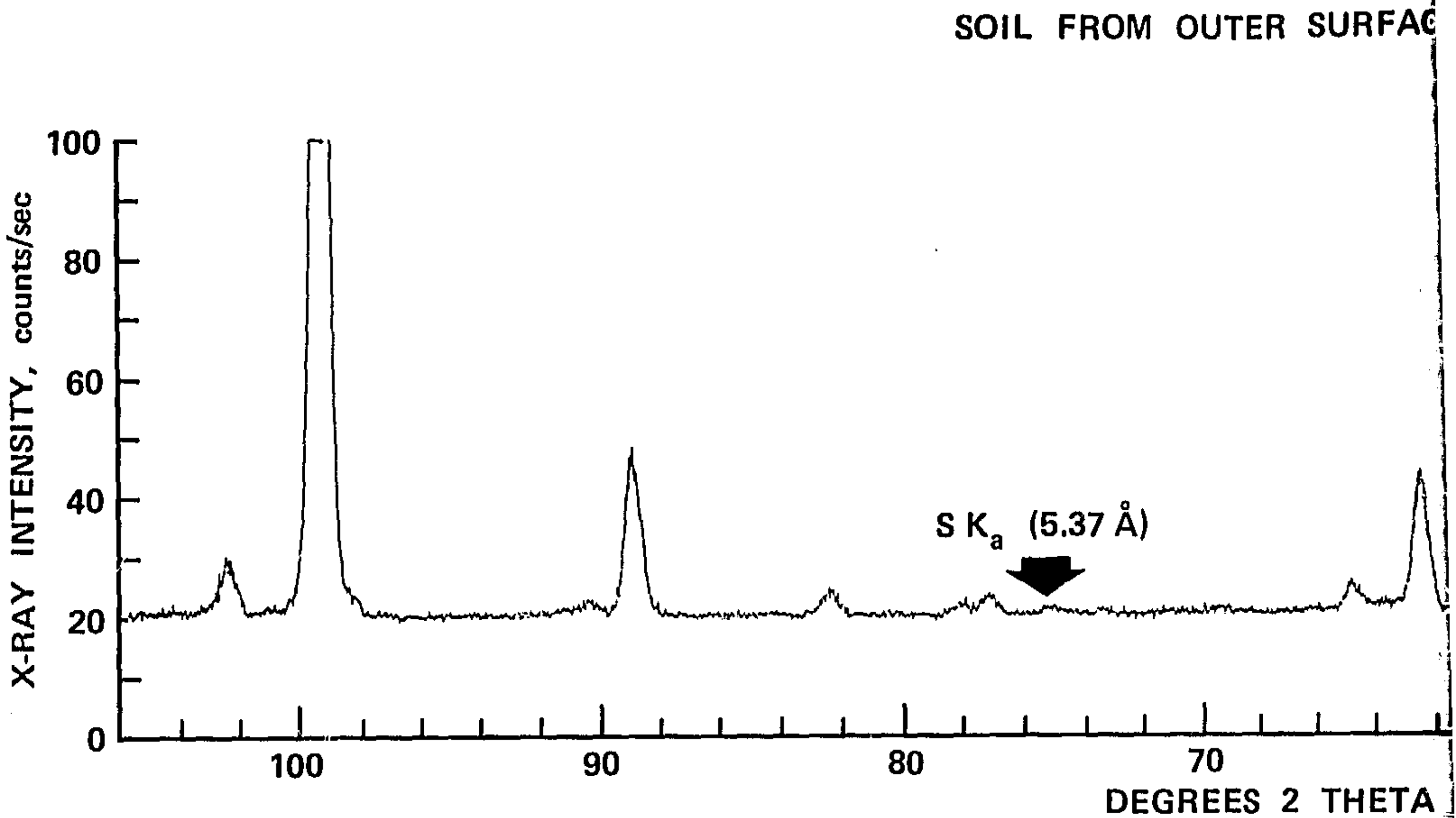


(a) Casing body.



(b) Nose cone.

Figure 7.— Photos of CRT display delineating the number of X-ray photons counted in 100 sec time and the energy of the emitted X-rays of the metal chips for the penetrator housing.



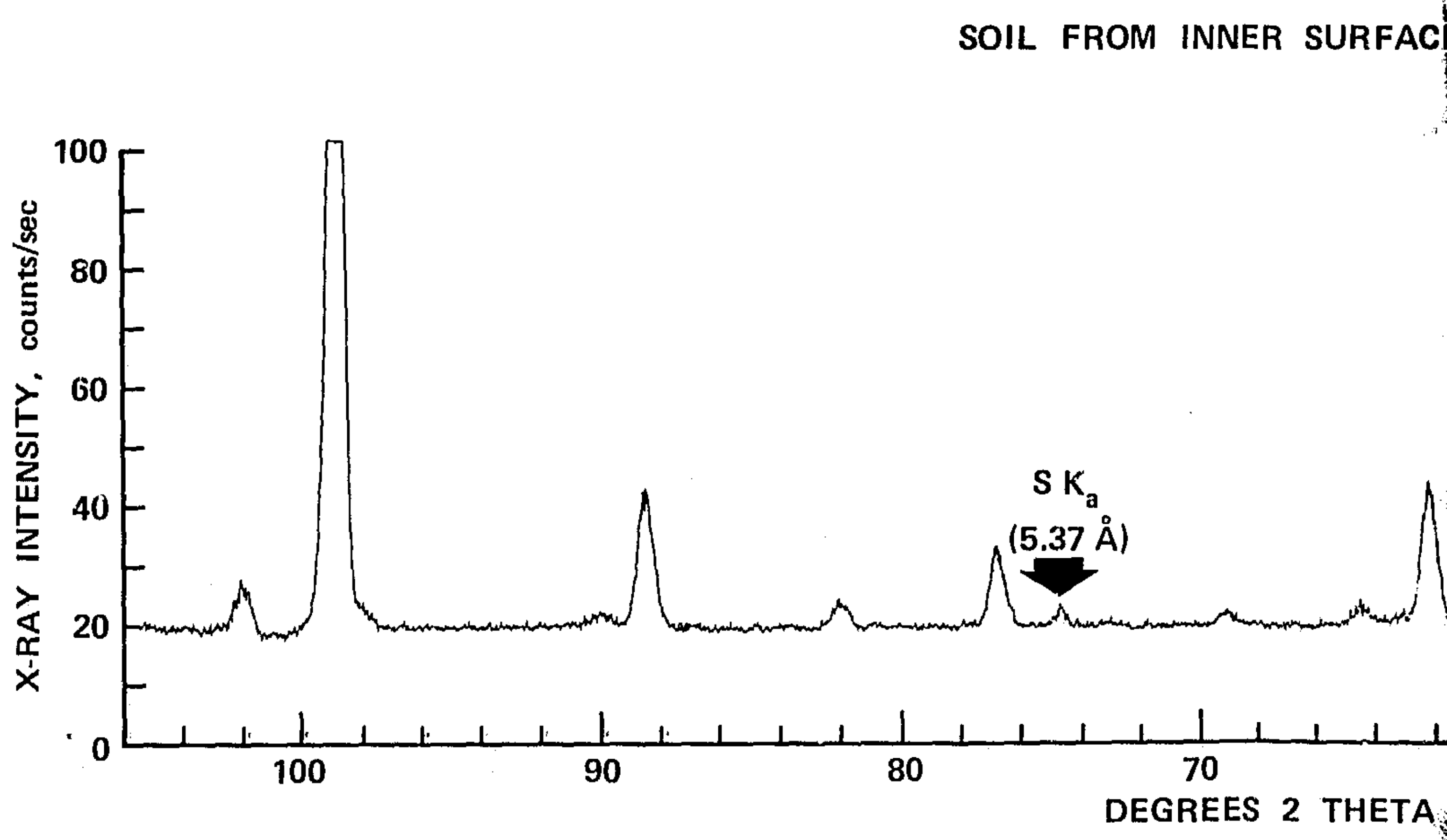


Figure 8.— Porti
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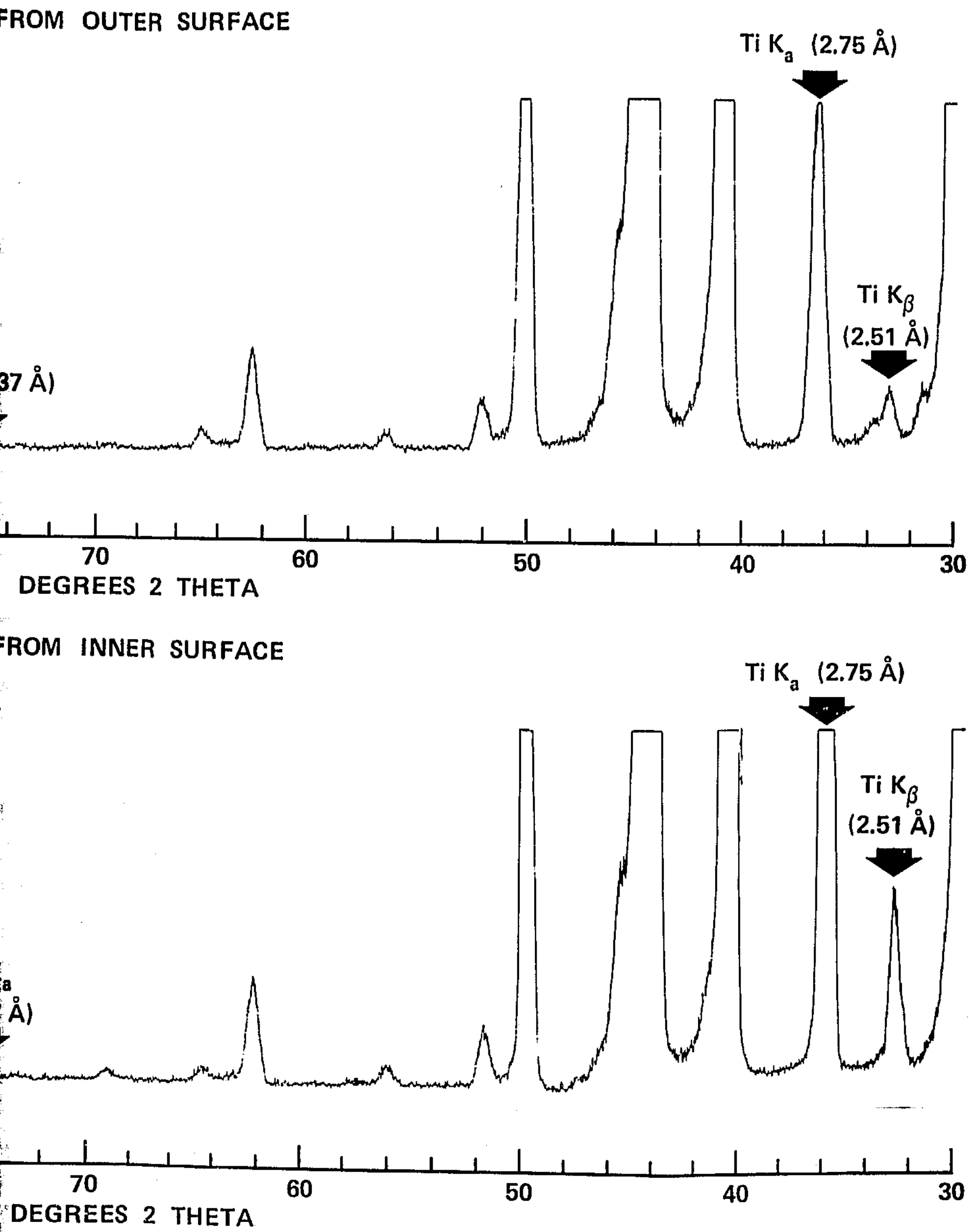

Figure 8.— Portion of strip chart from X-ray fluorescence analysis showing the increased concentration of S and Ti for the bulk soil samples tested.

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